The need of representation approach to provide prospective physics teacher with better reasoning ability and conceptual understanding

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Abstract

This article reports an explanatory QUAN-qual mixed method to assess students' conceptual understanding on mechanics and reasoning ability of the prospective physics teacher students (PPTS) in a public university in Indonesia. Quantitative data, i.e. PPTS's conceptual understanding on mechanics, was gathered using Mechanics Baseline Test (MBT) developed from the work of Hestenes and Wells (1992); whereas the qualitative data was gathered using rubrics to asses PPTS's reasoning ability that includes both technical and conceptual validity, based on students' open explanation on MBT. Subject of study consisted of 35 students who had taken Introductory Physics courses plus 24 students who had taken both Introductory Physics and Mechanics courses. This study shows: (1) PPTS's MBT score was quite low (mean = 7.41 (max = 22), SD = 3.95), (2) most PPTS's reasoning laid down on Level 1 (i.e. one level above the lowest level) for both technical (42%) and conceptual validity (about 45%), and (3) there are strong correlations among scores of MBT, technical aspect of reasoning, and conceptual validity aspect of reasoning. This study suggests the need of representation approach to provide PPTS with better reasoning ability and conceptual understanding.

Keywords: representation approach, MBT, reasoning ability

INTRODUCTION

This paper is guided by a vision that future physics teachers should have deep content knowledge and able to prepare their students for becoming scientifically literate citizens. Scientifically literate person is one who able to use scientific processes in making personal decision and to participate in discussion of scientific issues that affect society (NRC, 1996). In line with this vision, National Science Education Standard (NRC, 1996) emphasizes the importance of having students combine processes and scientific knowledge as they use scientific explanation and critical thinking to develop their understanding of science. Therefore, the prospective physics teachers need to have deep science knowledge and good reasoning ability.

Physics teachers need to have strong content knowledge. If a teacher themselves does not understand the nuances of a concept, the deep relationships between this particular concept and other concepts, and the ways through which this concept was constructed by the physics community, then translating these nuances into student understanding is impossible (Etkina, 2010). Physics teacher should have well-organized conceptual knowledge, not only within a particular branch of physics (e.g. mechanics, electrodynamics, etc), but also across branches of physics (e.g. mechanics and thermodynamics). In addition, teachers must understand the processes used to establish new knowledge and determine the validity of claims (Eylon and Bagno, 2006). Teachers also need to be able to communicate and clarify scientific ideas effectively to students. It implies that, in describing scientific ideas, teachers need to be able to use multiple modes of representation that lead to the opportunity to exchange and clarify meanings (Ainswoth *et al*., 2011).

Reasoning ability is a prerequisite for producing better scientific explanation. Scientific explanation includes a claim -a statement or conclusion that addresses the question or problem, evidence -data that supports the claim, and reasoning -reasons that justifies the connections between evidence and claim (McNeill and Krajcik, 2008). Constructing scientific explanations in which students support their claims with appropriate evidence and reasoning is an important element of scientific inquiry (NRC, 1996). Engaging in explanation can also help students develop a deeper understanding of the science content. Accordingly, Waldrip *et al*. (2010) conceptualized the science learning as the process and outcomes whereby students come to understand how to interpret and construct scientific explanations using the conventions of the subject.

The recent researches in science education argue that to learn science effectively, students need to understand the different representations of science concepts and processes, be able to translate a representation into one another, and understand their coordinated use in representing scientific knowledge (Hubber *et al*., 2010). There are also various studies that investigate the value of student-generated representations to promote understanding in science (Waldrip *et al*., 2010). According to those studies, students participation only in teacher-design activities may constrain opportunity for students' learning. It implies the need of learners to use their own representations. diSessa (2004) argued that students can productively design new representations, if be given enough time and support, even approaching qualities of scientific representation: precision (clear or unambiguous), conciseness (give minimal but sufficient information), and completeness (comprehensive for its purpose). However, Carolan *et al*. (2008)

reminded that students need guidance in making links between their own representations and authorized ones from the science community.

This paper reports a preliminary study that explored reasoning ability and conceptual understanding in mechanics of the prospective physics teacher students (PPTS) in a public university in Indonesia. PPTS's conceptual understanding was assessed using Mechanical Baseline Test (MBT), and reasoning ability was assessed using rubrics to code students' written explanation on MBT. Research questions included: (1) What is the PPTS's score of MBT? (2) What is the PPTS's reasoning ability (both in aspect of technical and conceptual validity)? (3) What is the relationship among PPTS's scores of MBT, technical reasoning, and conceptual validity? Based on the result of this study, we argue the importance to implement an alternative approach to provide PPTS with the opportunities to improve their reasoning ability and acquire better conceptual understanding. The approach is representation approach in which students being able to state claims, reflect on what is appropriate evidence, as well as critique, modify, and then refine their reasoning representations.

METHODOLOGY

Subject and time

This study was conducted on September 2011. Subject of study consisted of 59 students. They were the undergraduate students of physics education program in one public university in Indonesia. All of them had taken Introductory Physics courses and 24 of them had taken Mechanics as well. Introductory Physics courses implement an approach that combines calculus and non-calculus base, whereas mechanics course uses more calculus and analytical approach. A representational approach has not been exposed in those courses.

Research design

Research design was explanatory mixed method (Creswell and Clark, 2007). The research started with collecting quantitative data of students' score on MBT. Subject of study covered all of 59 students. A descriptive analysis was implemented to get information about min, max, first to third quartile, and mean of MBT score distribution. The second step was gathering qualitative data of students' reasoning ability based on students' explanation written on MBT answer sheet. Subjects of qualitative study consisted of 24 students who had taken both Introductory Physics and Mechanics courses. The qualitative data was also quantified using scoring rubrics and then described using descriptive analysis of students' score on reasoning ability (both technical and conceptual validity). The correlation analysis then implemented to get correlation among scores of MBT, technical reasoning ability, and conceptual validity used in reasoning. The final step was formulating the overall findings and interpretations. Figure 1 shows the research design in a brief.

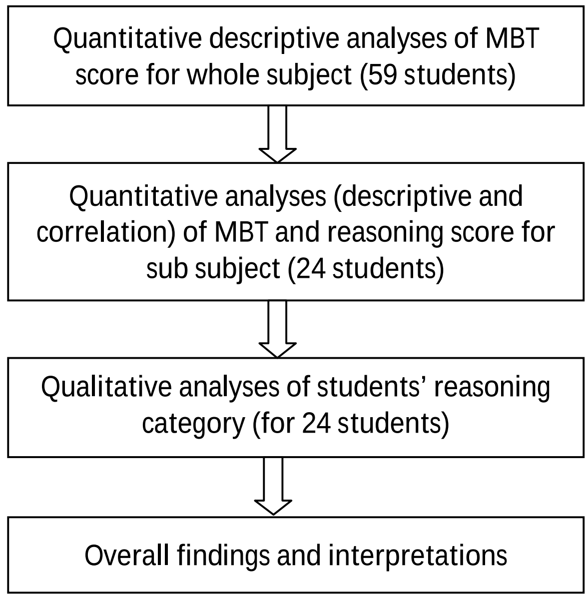

Figure 1. QUAN-qual mixed method used in this study

Instruments

The instrument of MBT consists of 22 items extracted from the 25 original items adopted from the work of Hestenes and Wells (1992); three of 25 items were dropped based on the pilot study conducted in the middle of August 2011. The coefficient of Pearson' product moment correlation between item score with total score varies from r (52) = 0.32 ($p < 0.05$) to r (52) = 0.62 ($p < 0.01$). Three items have correlation coefficient that significant on $p < 0.05$ and the rest are on $p < 0.01$. The instrument has Cronbach's Alpha of 0.81. It means that the instrument has "very good" internal consistency (Everitt and Skrondal, 2010) and provides good support for internal consistency reliability (Morgan *et al.,* 2004). The discrimination index of items varies from 0.29 (moderate) to 0.86 (very high) and index of easiness varies from 0.12 (difficult) to 0.63 (moderate).There were two types of direction to response the test. The Introductory Physics sub group (N = 35) chose one option that best represented their response whereas, for the others students, i.e. introductory-mechanics group (N = 24), they were asked to give open explanation in addition to choosing one best option. This different direction might influence student's score on MBT. It was a shortcoming of this method. The main purpose of the extra requirement was to gather qualitative data needed for further analysis as shown in Figure 1.

To assess students' reasoning ability, two kinds of rubric shown in Table 1 and 2 were implemented to code students' open explanation. The rubrics were resulted from revision of former version based on the pilot study. For checking the coding reliability, 25% of reasoning units (follows the works of Hardy *et al*; 2010) on each data set had been coded by primary coder (researcher) and one secondary independent coder. There were 22 × 24 = 528 units of reasoning in total for each data set. The percentage agreements of two coders were 90% for technical reasoning and 95% for conceptual validity. The codes of the primary coder were used for further analyses.

Table 1. Rubric to code student's reasoning quality (technical aspect)

Category	Score	Definition	Description/indicator	More detailed description
Rule-based	4	Inductive/ deductive rule-based	Claim is backed up by generalized relationship, principle, theory, or law.	The rationale consists of a comprehensive data analyses supported by principle, theory, law, or definition that are relevant to the data and problem being analyzed. The scientific correctness of the theory, law, etc. used in this argumentation is not an important point.
Relational	3	Evidence-based reasoning	Claim is backed up by evidence, including analogy and analysis of data	The rational considers an amount of data (including implicit data, but not enough to solve problem correctly) and applies a relevant data analyses.
Phenomenological	2	Data-based reasoning	Claim is backed up by data	The rational relays on the limited data or the surface feature of the problem
Unsupported	1	No reasoning (claim-based reasoning)	Claim is not backed up (no rationale),	There is response but no rationale
			The backup is a pseudo, circular, or tautological	There is a rationale but it is merely just: • a restatement of the claim (response); or • a statement that is not clearly relate to the problem nor clear in meaning
Unidentified	0	No claim	No answer	Student's answer sheet is blank

Modified from Hardy *et al*. (2010) and Furtak *et al*. (2010)

Table 2. Rubric to code student's reasoning quality (conceptual validity)

Category	Score	Definition	Schema claim-rationale	
			Claim	Rationale
Fully valid	3	Claim is correct and follows from the appropriate (relevant and correct) backup	Ok	Fully correct and relevant
Partially valid	2	• Claim is correct but the backup is not fully appropriate (the backup is true but irrelevant or incomplete), or • Claim is incorrect since it follows from inappropriate (true but irrelevant or incomplete) backup	Ok/ false	True but irrelevant or incomplete
Invalid	1	Claim is incorrect since: • It does not logically follow from backup, or • It follows a fully incorrect backup	False	Incorrect
		Claim is correct BUT fully follows incorrect backup	Ok	Fully incorrect
Unidentified	0	No rationale, or the rational is tautological	Ok/ false	--- or tautological

RESULT AND DISCUSSION

MBT score

Table 3 shows the descriptive statistics of MBT score for whole subject (59 students who had taken Mechanics and/or Introductory Physics courses) and for sub subject (group of 24 students who had taken both Mechanics and Introductory Physics courses and of 35 students who had not yet taken Mechanics).

Table 3. Descriptive statistics of MBT score, grouped by whole subjects and sub subjects

Statistics	Whole subjects ($N = 59$)	Sub Subject	
		Mechanics & Introductory Physics group ($N = 24$)	Introductory Physics group ($N = 35$)
Minimum	1	3	1
Maximum	15	14	15
First quartile	4.00	6.50	4.00
Median	7.00	8.50	5.00
Third quartile	11.00	12.50	7.50
Mean & its std. error	7.41 (0.51)	8.79 (0,71)	6.46 (0.68)
Standard deviation	3.95	3.46	4.03
Skewness & its std. error	0.50 (0.31)	0.01 (0.47)	1.01 (0.40)
Kurtosis & its std. error	– 0.87 (0.61)	– 1.08 (0.92)	0.04 (0.78)

Data on Table 3 show that students' MBT score was quite low. The maximum score was 15 or about 68% of the expected maximum score (22), and more surprisingly, it was achieved by students who had not yet taken Mechanics. The median (in whole subjects) shows that 50% of students got score less than or equal to 7.00, and the value of third quartile shows that 75% of students got score less than or equal to 11.00 or 50% of the expected maximum score. However, the lowness of students' achievement in MBT is likely also occurs in other country than Indonesia. For example, Potgieter *et al.* (2010) reported that fresh students of South African University achieved average score of 11.36 (max = 20) on mechanics test constructed from MBT and FCI.

The means difference between sub subjects, i.e. 8.79 – 6.46 = 2.33, is significant at $p = 0.05$ (2-tails). The result of Mann-Whitney U test yields $z = -2.51$ and $p = 0.012 < 0.05$. Therefore, it can be concluded that Mechanics-Introductory physics group achieved higher MBT score than that of Introductory physics group. The *d*-effect size of this difference is about 0.61 in the unit of pooled standard deviation. It is calculated using formula $d = (M_A - M_B)/SD_{pooled}$ (Morgan *et al*; 2004: 90), where SD_{pooled} is $SD_{pooled} = \sqrt{\frac{(n_A-1)SD_A^2+(n_B-1)SD_B^2}{n_A+n_B-2}} = 3.81$.

However, there is remain a question on the factor(s) that really cause the difference.

Reasoning quality

Students' reasoning quality was assessed using rubrics (Table 1 and 2) based on students' open explanation on MBT. Subjects of study included only group of students who had taken both Mechanics and Introductory Physics course. Therefore, it is important to look at first the similarity of sub subjects and whole subjects.

Table 3 shows that the skewness of the two data sets are within the interval of $\pm$ 1.0. It means that they are normally distributed or at least approximately normal (Morgan *et al*., 2004). Therefore, it is possible to use t-test for checking the difference between their means. Using SPSS 16.0, the t-test values are $t = 1.50$, $df = 81$, and $p = 0.14$ (2-tails). Since $p > 0.05$ then the difference between those means is not significant for $p = 0.05$ (2-tails). The boxplots of descriptive statistics of those data sets are shown in Figure 2. This statistical conclusion allows us to perform further analysis based on the data sets drawing from sub subject of 24 students.

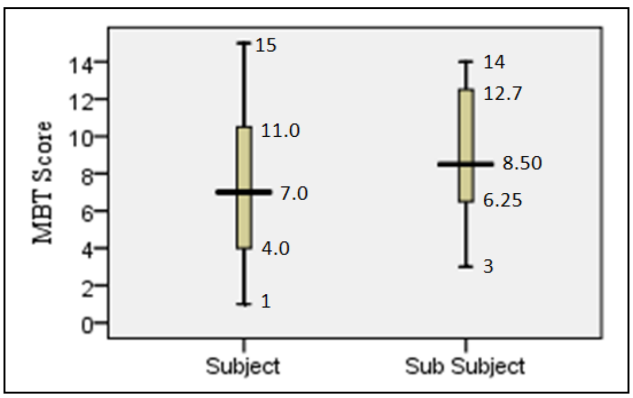

Figure 2. Boxplots of MBT Score by whole subjects (N = 59) and sub subjects (N = 24)

The coding results of students' reasoning ability are summarized in Table 4 and Figure 3. It is clear that most students' reasoning laid down on Level 1 (i.e. one level above the lowest level) for both technical (42%) and conceptual validity (about 45%). It means that in performing reasoning, most students tend to make a claim without adequate backup. Their claims were not mostly backed up, or the back up were pseudo, circular, or tautological. On the other hands, the validity of their conceptual understanding employed in reasoning were also mostly invalid. Their incorrect claims might caused by incorrectness of their understanding of physics concepts underlining the problems, or by misleading in drawing conclusion.

Table 4. Frequency distribution of reasoning level, grouped by technical and conceptual validity.

Aspects		Lev.0	Lev.1	Lev.2	Lev.3	Lev.4	Total
Technical	*f*:	8	222	138	34	126	528
	%:	1.52	42	26.1	6.44	23.9	100
Conceptual validity	*f*:	105	237	87	99	NA	528
	%:	19.9	44.9	16.5	18.8	NA	100

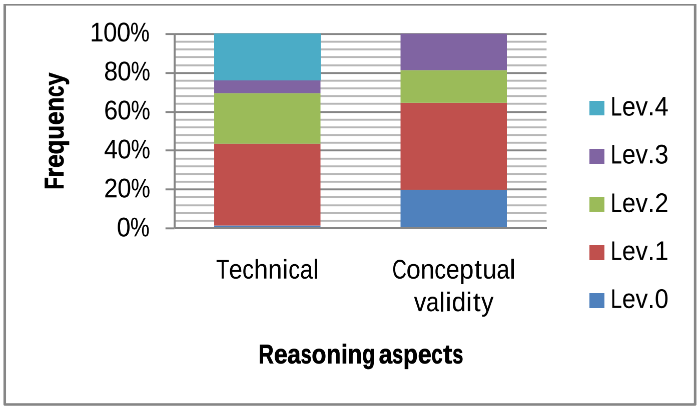

Figure 3. Levels of reasoning ability by technical and conceptual validity

There were also many students who made correct claim but wrote an incorrect reason. For example is students' response on the problem shown in Figure 4. The correct answer is C.

A block is sliding along a frictionless ramp as shown in the figure. What is the arrow that best represents the acceleration of the block when the block is in the position of I?

(A) 1 (B) 2 (C) 4 (D) 5

(E) None of the arrows; the acceleration is zero.

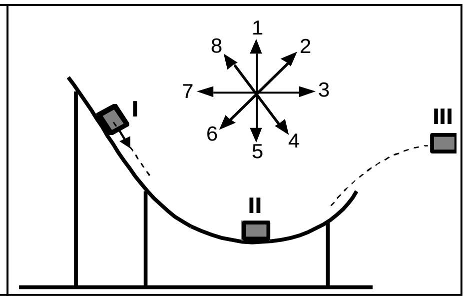

Figure 4. An example of a problem that most students incorrectly answered.

Unfortunately, their reasons did not justify their response. Most students (12 of 16 students who chose option C in sub group of 24 students) wrote reason based on (incorrect) principle: "the direction of acceleration is (always) in the direction of motion, or same as the direction of velocity". Although such reason has successfully brought students to the correct answer, especially in this particular problem, the reason is clearly inappropriate. Such reason should bring students to a claim that the acceleration in position II, for instance, is in the direction of arrow 3; a claim which clearly incorrect. Students did not notice, for example, how velocity changes from a point just before to a point just after position I. It meant that students did not apply a very definition of acceleration: $\mathbf{a} = \frac{d\mathbf{v}}{dt}$ or $\lim_{\Delta t \to 0} \frac{\Delta \mathbf{v}}{\Delta t}$ in solving the problem.

Correlation among scores of MBT, technical reasoning, and conceptual validity

Scoring students' reasoning using rubrics shown in Table 1 and 2 yields descriptive statistics shown in Table 5. It is clear that both data sets are normally distributed. Therefore, it is possible to calculate correlation coeficients among data sets of MBT and reasoning scores using Pearson's product moment correlation. Figure 5 shows the resulted matrix correlations among the three data sets.

Table 5. Descriptive statistics of students' average reasoning score

Aspect	Min	Max	Mean	SD	Skewness	Kurtosis
Technical (max=4)	1.32	3.00	2.09	0.41	0.26	-0.51
Conceptual validity (max=3)	0.68	2.14	1.34	0.41	0.12	-1.04

	MBT	Technical reasoning	Conceptual validity
MBT	1	$r = 0.68$, $p < 0.01$	$r = 0.79$, $p < 0.01$
Technical reasoning		1	$r = 0.81$, $p < 0.01$
Conceptual validity			1

Figure 5. Matrix correlation among scores of MBT and reasoning aspects (N = 24).

Figure 6 shows that there are strong correlation among scores of MBT, technical aspect of reasoning, and conceptual validity aspect of reasoning. Therefore, it is critical to find out a new learning approach that allows students (PPTS) to acquire better reasoning ability and deeper conceptual understanding, especially concerning on physics topics that they will teach to their future students. A representational approach to learning in which students being able to state claims, reflect on what is appropriate evidence, as well as critique and modify the representation and then refine both the reasoning process and the initial representation, is assumed to be appropriate to provide students with those abilities.

Representation approach in science teaching is an argument-based inquiry in which students negotiate their understanding of science concepts by engaging in the practices of science. The core activity is "reasoning through representing". Students both construct and critique science knowledge through processes that include the posing of questions, the construction of claims and the communication of evidence to support these claims (Waldrip *et al*., 2010). Students not only respond to sanctioned representations, i.e. the representations developed by experts and typically presented in physics textbooks, but also develop their own representations. The approach encourages students to think critically and reason logically as they negotiate understanding through talking, reading, and writing. Therefore, the prospective physics teachers need such learning experiences that potentially give them the opportunities to acquire deeper content knowledge as well as to develop reasoning.

CONCLUSION

1. The MBT score of prospective physics teachers involved in this research was quite low. Its mean was 7.41 (max = 22) with SD of 3.95.
2. The reasoning quality was also quite low. Its mean was about 2.1 (max = 4) for technical aspect and about 1.3 (max = 3) for conceptual validity. Most reasoning levels laid down on Level 1 (i.e. one level above the lowest level) for both technical (42%) and conceptual validity (about 45%).
3. There are strong correlations among scores of MBT, technical aspect of reasoning, and conceptual validity aspect of reasoning. The corresponding correlation coefficients varies from r (24) = 0.68 to r (24) = 0.81, $p < 0.01$. This finding suggests the need of new approach for giving students (PPTS) with much more opportunities to both develop their reason ability and acquire better conceptual understanding.
4. A representation approach in which students (PPTS) being able to state claims, reflect on what is appropriate evidence, as well as critique and modify the representation and then refine both the reasoning process and the their representations, is assumed to be appropriate to provide students with those abilities. However, it needs further study to find out the adequate evidences as well as the possible strategies for implementing the approach.

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